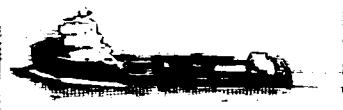


AD-A270 778



US Army Corps  
of Engineers



93-23777



DREDGING RESEARCH PROGRAM

(2)

MISCELLANEOUS PAPER DRP-93-1

## USE OF A SIMPLE MODEL TO CALCULATE VELOCITY PROFILES OVER CHANGING BED SLOPES

by

R. C. Berger, Allen M. Teeter, Walter Pankow

Hydraulics Laboratory

DEPARTMENT OF THE ARMY  
Waterways Experiment Station, Corps of Engineers  
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



DTIC  
ELECTE  
OCT 12 1993  
S P B D

September 1993

Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY  
US Army Corps of Engineers  
Washington, DC 20314-1000

Monitored by Coastal Engineering Research Center  
US Army Engineer Waterways Experiment Station  
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

Under Work Unit No. 32590

9 3 1 3 0 3 9

The Dredging Research Program (DRP) is a seven-year program of the US Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Water**
- Area 2 - Material Properties Related to Navigation and Dredging**
- Area 3 - Dredge Plant Equipment and Systems Processes**
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems**
- Area 5 - Management of Dredging Projects**

**Destroy this report when no longer needed. Do not return  
it to the originator.**

**The contents of this report are not to be used for  
advertising, publication, or promotional purposes.  
Citation of trade names does not constitute an official  
endorsement or approval of the use of such  
commercial products.**



US Army Corps  
of Engineers  
Waterways Experiment  
Station

# Dredging Research Program Report Summary



## *Use of a Simple Model to Calculate Velocity Profiles over Changing Bed Slopes (MP DRP-93-1)*

**ISSUE:** Dispersion of sediment material from a disposal site must often be assessed by Corps dredging operation elements. Predictions are needed in cases where the disposal site capacity or retention is to be assessed for some purpose. In certain special cases, dredged material is placed in an underwater trench. Whether the dredged material is configured as a mound or placed in a trench, special procedures are required to predict shear stress on the material and, ultimately, sediment transport.

**RESEARCH:** The Dredging Research Program (DRP) includes developing guidance and procedures for predicting movements of dredged material placed in open water. An important part of DRP research is to check predictive techniques against data, as was done here.

**SUMMARY:** A simple numerical model is described to predict velocity profiles in the vertical direction and bed shear stresses at various locations along a mound or trench. The computer program HPROFILE operates on a personal computer and is easy to use. The model is intended to allow engineers to make calculations as part of an assessment as to whether dredged material will remain or move from its placement site.

**AVAILABILITY OF REPORT:** The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) report numbers may be requested from WES Librarians.

To purchase a copy of the report, call NTIS at (703) 487-4780.

**About the Authors:** Dr. R. C. Berger is a Research Hydraulic Engineer in the Estuaries Division (ED), Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES). Mr. Allen M. Teeter is a Research Oceanographer and Mr. Walter Pankow is a Hydraulics Engineer in ED. For further information on this work, contact Mr. Teeter at (601) 634-2820. For general information on the DRP, contact Mr. E. Clark McNair, Manager, DRP, at (601) 634-2070.

# Use of a Simple Model to Calculate Velocity Profiles over Changing Bed Slopes

by R. C. Berger, Allen M. Teeter, Walter Pankow

Hydraulics Laboratory

U.S. Army Corps of Engineers  
Waterways Experiment Station  
3909 Halls Ferry Road  
Vicksburg, MS 39180-6199

DTIC QUALITY INSPECTED 2

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers  
Washington, DC 20314-1000

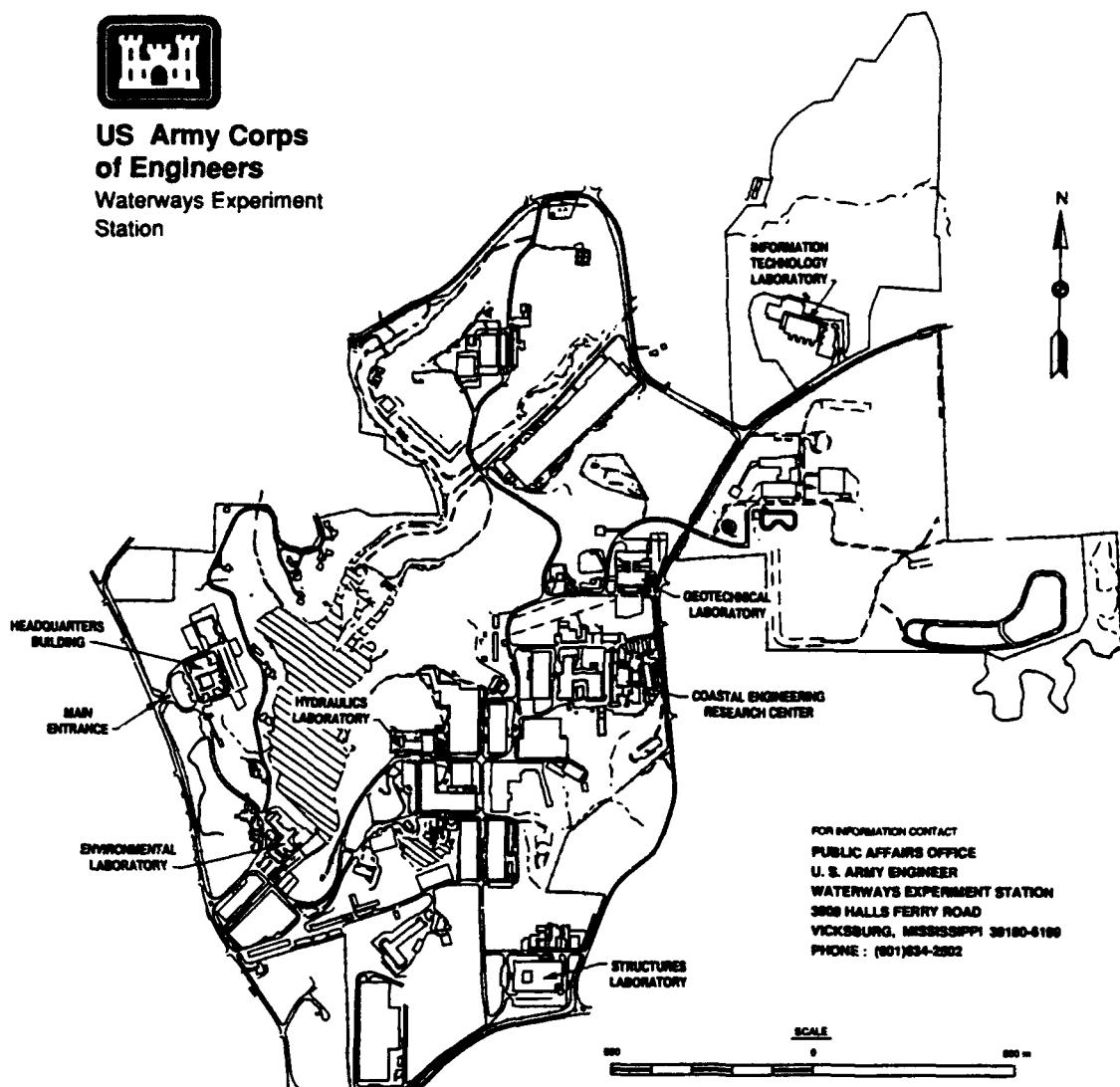
Monitored by Coastal Engineering Research Center  
U.S. Army Engineer Waterways Experiment Station  
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

Under Work Unit 32590

|                    |                                     |
|--------------------|-------------------------------------|
| Accession For      |                                     |
| NTIS GRA&I         | <input checked="" type="checkbox"/> |
| DTIC TAB           | <input type="checkbox"/>            |
| Unannounced        | <input type="checkbox"/>            |
| Justification      |                                     |
| By                 |                                     |
| Distribution/      |                                     |
| Availability Codes |                                     |
| Dist               | Avail and/or<br>Special             |
| R                  |                                     |



**US Army Corps  
of Engineers**  
Waterways Experiment  
Station



FOR INFORMATION CONTACT  
PUBLIC AFFAIRS OFFICE  
U. S. ARMY ENGINEER  
WATERWAYS EXPERIMENT STATION  
3000 HALLS FERRY ROAD  
VICKSBURG, MISSISSIPPI 39180-6160  
PHONE : (601)634-2802

**Waterways Experiment Station Cataloging-in-Publication Data**

Berger, Rutherford C.

Use of a simple model to calculate velocity profiles over changing bed slopes / by R.C. Berger, Allen M. Teeter, Walter Pankow ; prepared for U.S. Army Corps of Engineers ; monitored by Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station.

40 p. : ill. ; 28 cm. — (Miscellaneous paper ; DRP-93-1)

1. Streamflow velocity — Computer programs. 2. River channels — Mathematical models. 3. Dredging spoil — Environmental aspects — Data processing. I. Teeter, Allen M. II. Pankow, Walter. III. United States. Army. Corps of Engineers. IV. Coastal Engineering Research Center (U.S.) V. U.S. Army Engineer Waterways Experiment Station VI. Dredging Research Program. VII. Title. VIII. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; DRP-93-1.

TA7 W34m no.DRP-93-1

# Contents

---

|  |            |
|--|------------|
| <b>Preface</b> .....                             | <b>vi</b>  |
| <b>Summary</b> .....                             | <b>vii</b> |
| <b>1—Introduction</b> .....                      | <b>1</b>   |
| <b>Background</b> .....                          | <b>1</b>   |
| <b>Discussion</b> .....                          | <b>1</b>   |
| <b>Model and Flume Data Comparison</b> .....     | <b>3</b>   |
| <b>Flume and Model Comparisons</b> .....         | <b>3</b>   |
| <b>2—Details of Van Rijn's Formulation</b> ..... | <b>5</b>   |
| <b>3—The Model Code</b> .....                    | <b>8</b>   |
| <b>4—Summary</b> .....                           | <b>10</b>  |
| <b>Figures 1-19</b>                              |            |
| <b>Appendix A: Model Stability</b> .....         | <b>A1</b>  |
| <b>Appendix B: HPROFILE User's Guide</b> .....   | <b>B1</b>  |
| <b>Software Installation</b> .....               | <b>B1</b>  |
| <b>Model Operation</b> .....                     | <b>B2</b>  |
| <b>Main Menu Option Descriptions</b> .....       | <b>B2</b>  |

SF 298

# Preface

---

This study was conducted at the Hydraulics Laboratory (HL) for the Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station (WES). The work described herein was authorized as part of the Dredging Research Program (DRP) by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and was performed under Work Unit 32590, "Calculation of Boundary Layer Properties (Cohesive Sediments)." Messrs. Glenn R. Drummond, Rixie J. Hardy, Vincent Montante, and John J. Perez are DRP Technical Monitors from HQUSACE. Mr. E. Clark McNair, Jr., CERC, is Program Manager (PM) for the DRP, and Dr. Lyndell Z. Hales, CERC, is Assistant PM. Dr. Nicholas C. Kraus, Senior Scientist, CERC, is the Manager for DRP Technical Area 1, "Analysis of Dredged Material Placed in Open Waters."

The study was conducted by Mr. R. C. Berger, Estuarine Simulation Branch, Estuaries Division (ED), HL, in conjunction with the Work Unit Principal Investigator, Mr. A. M. Teeter, Estuarine Processes Branch (EPB), ED. This report was prepared by Messrs. Berger, Teeter, and W. Pankow, EPB, under the direct supervision of Mr. W. H. McAnally, Jr., Chief, ED, and the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL, and R. A. Sager, Assistant Director, HL. Ms. L. Pace, under a contract agreement with Mississippi College, Clinton, MS, prepared Appendix B. The graphics software used in the personal computer program (HGRAPH) was developed by Mr. D. W. Hyde, Structural Mechanics Division, Structures Laboratory, WES. Mr. Steve Knowles, EPB, collected the flume data.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

For further information on this report or on the Dredging Research Program, please contact Mr. E. Clark McNair, Program Manager, at (601) 634-2070, or Mr. Allen M. Teeter, Principal Investigator, at (601) 634-2820.

# Summary

---

This report reviews a simplified numerical model to calculate the velocity profile in the vertical direction for changing bed slopes subjected to currents. Model predictions were compared to flume data for flow over a mound and a trench to determine if the model would be a reasonable planning tool for calculations involving dredged material disposal sites.

The flume data used were a difficult test for this model, but the overall profiles compare reasonably well. Therefore, the model is judged reliable for planning purposes involving dredged material disposal. Although the model will predict the vertical velocity profiles in low riverine- and tide-dominant flows, wave action is not included.

# 1 Introduction

---

## Background

The cost effectiveness of material disposal from maintenance dredging operations depends upon the distance from the dredging site and also upon the hydraulic suitability of the site, the type of material being deposited, and available equipment. The deposited material may be subjected to currents that can cause it to be eroded and transported away from the site. The severity of this condition as well as the fate of the material need to be addressed in the early planning phase. The precision of the planning estimates depends on desk studies typically performed on a personal computer. In order to estimate the amount of scour and transport at the disposal site, the bottom shear stresses must be developed; therefore, the vertical velocity profile within and adjacent to the site is of interest. For uniform bathymetry conditions, a typical logarithmic velocity profile suffices; however, a more general method is needed for variable depths. This report outlines a method to calculate vertical velocity profiles over variable depths, and presents comparisons with flume data to indicate the limitations of the computer code. The model, HPROFILE, predicts the vertical velocity profile at various depths in the low riverine- and tide-dominant flows, but does not include wave actions.

## Discussion

In a uniform flow, it is customary to assume the vertical velocity profile to be logarithmic as shown in Equation 1:

$$U(z) = \frac{u_*}{\kappa} \ln \left( \frac{z}{z_0} \right) \quad (1)$$

where

$U$  = the longitudinal (horizontal) velocity

$z$  = the distance above the bed

$u_*$  = friction velocity  $(\tau/\rho)^{1/2}$

$\tau$  = shear stress on the bed

$\rho$  = fluid density

$\kappa$  = von Karman's constant (approximately 0.40)

$z_0$  = the distance above the bed at which the velocity is assumed zero; the roughness length

However, when the bathymetry changes, the flow field is impacted by the modification of the flow boundary layer. Disposal sites may indeed have severe depth variations such as trenches or formed mounds, and it is important that a reasonable velocity profile be calculated under these conditions. The simplest method that is appropriate is van Rijn's method.<sup>1</sup> The basic assumptions of van Rijn are that the vertical velocity profile can be described as logarithmic plus a perturbation profile due to the bathymetric effects; and that the actual profile (with bathymetric effects) and the equilibrium profile (logarithmic) are identical at middepth. The manner in which the profile is perturbed to account for the changes in depth is empirical. Details of van Rijn's method are given in Chapter 2.

There are some obvious limitations to this method. The first is that it is based upon empirical data (measurements) and may compare poorly to measurements beyond the range used for its development. Secondly, it is steady-state. This, however, is probably not limiting since one can step through a tidal cycle with fair precision as, in general, the temporal terms are small. Van Rijn, on the other hand, was able to get reasonably good results with this simple scheme. In fact, it compares quite well with a much more sophisticated hydrodynamic model using  $k$ - $\epsilon$  turbulence closure. Some of van Rijn's results are shown in Figure 1 (where this simple model is referred to as the profile model).

Figure 1 indicates that the method is capable of representing flow reversal due to an expansion of a mound. However, the eddy is less pronounced and spread over a larger depth. This is probably due to the limited degree of the function included as the perturbation profile. Although one could see how assuming that the middepth velocity matches the equilibrium profile could cause this effect, it is a remarkable comparison for such a simple model. It also demonstrates the relative increase in lower level velocity as the current flow moves up a slope and conversely the relative reduction of the deeper velocity on the downward slope.

---

<sup>1</sup> L. C. van Rijn. (1987). "Mathematical modelling of morphological processes in the case of suspended sediment transport," Delft Hydraulics Communication No. 382, Delft Hydraulics Laboratory, Delft, The Netherlands.

## Flume Data

Data sets with bed roughness outside the range originally used by van Rijn were collected in a Hydraulics Laboratory test flume at the U.S. Army Engineer Waterways Experiment Station. There are two data sets, one representing a mound and one a trench. The flume was 34 m long by approximately 2 m wide, and the testing took place in the approximate center of the flume. The mound was 2.15 m long with a rise of 0.051 m and 1V:3.5H side slopes, and the trench was 1.56 m long and 0.048 m deep with 1V:6.5H side slopes. The mound was constructed with wood and the trench was troweled concrete with surfaces being rather smooth. The remainder of the flume surface was brushed concrete texture.

The flume data collected consisted of bottom shear stresses and current velocity measured over the vertical as well as horizontal components. Figures 2 and 3 indicate the measured bottom shear stress in the flume as well as the bathymetry of each configuration. Figure 2, the trench test, indicates that the stresses are slightly higher downstream, probably due to the increased bottom velocity as flow moved up the slope. Figure 3, the mound test, is more difficult to interpret: on the upstream slope (.ne dip in stress) prior to the mound crest (location 2.41 m), the flow appears to be at a stagnation point; however, this is not the case. The slope is 1V:3.5H; however, the plot has a distorted scale that makes the slope appear much steeper than it really is. Downstream of the mound, the bottom velocity is actually lower as is shown by the shear stress. The spike (location 0.098 m) is within the middle of a flow reversal close to the bottom. The velocity profile data collected in the flume will be presented with a comparison to numerical model data.

## Flume and Model Comparisons

The numerical model (HPROFILE) was run for comparison to the flume data with the following parameters:

a. Discharge:

$$Q = 0.104 \text{ m}^3/\text{sec}/\text{m}$$

b. Distance above bed for zero velocity:

$$z_0 = 1 \times 10^{-6} \text{ m}$$

Calculations were made at 21 locations for the mound tests and 22 locations for the trench tests. The average distance between stations was about half the depth. The model requires numerical integration from station to station in order to calculate the surface velocity. The technique used is a Runge-Kutta fourth-order scheme so that there is some stability limit on how large the

distance between stations can be. Details of the model and its application are presented in Chapter 3. An analysis of the stability limit, presented in Appendix A, demonstrates that, for practical purposes, the limit is sufficiently large that it should not interfere with normal operations. In general, the distance between stations should be less than twice the depth, and the size of adjoining cells should not vary too quickly. The larger of the two adjoining cells should be less than twice the size of the smaller since gradual transitions are more precise.

Velocity profiles at several flume locations are shown in Figures 4-19. Figures 4-10 are the mound test comparisons and Figures 11-19 are the trench tests. The figures progress in the downstream direction. It should be noted that the model is presently programmed to handle only positive velocities (i.e., velocity in the direction of positive  $x$ ). In order to compare the flume data, the model output direction was reversed. The upstream profile is assumed to be an equilibrium profile, and  $z_0$  was adjusted until the upstream reproduction was good. Figures 4-6 show the change in profile as the flow moved upslope. The model seemed to react more quickly than the flume data suggest, becoming uniform sooner than the flume results. Station 1.98 m (Figure 7) improved. However, as the flow moved down the back slope (Figures 8-10), the model was unable to pick up the near-bottom flow reversal (Figure 9). It is not surprising that this is the case since the separation was so near the bed and since the perturbation profile includes only two additional functions. At the downstream end (station -0.30, Figure 10) the profile compares more closely, but it is evident that the model was reacting more quickly to bed changes than was the flume. The flume profile is more uniform in the surface layers than the model is.

The tests conducted provided severe conditions for the model to reproduce. The velocity gradients were steep and confined to a small region, and the perturbation profile could not reproduce these conditions very well. When the profile is more gradual, the model does relatively well. The transitions with the bathymetric changes appear somewhat fast in the model. Any correction for this would need to be made via the empirical constants used to predict the change in surface velocity. However, not enough data are available at this time to be sure of this conclusion nor to make the appropriate modification. Overall the comparisons are sufficiently precise for the model to function as a planning tool.

## 2 Details of Van Rijn's Formulation

---

The basic premise of the method is that a nonuniform flow profile can be described as a linear combination of a logarithmic profile representing the law of the wall and a perturbation profile representing the influence of pressure gradients:

$$U(z) = A U_h \ln \left( \frac{z}{z_0} \right) + U_h \left[ 1 - A \ln \left( \frac{h}{z_0} \right) \right] (2n^t - n^{2t}) \quad (2)$$

where

$U(z)$  = velocity at distance  $z$  above the bed

$A, t$  = constants for a particular longitudinal location

$U_h$  = velocity at the water surface

$h$  = depth

$n = (z - z_0)/(h - z_0)$

This yields three unknown quantities ( $A, t, U_h$ ) requiring three equations for solution.

The calculation of  $A$  uses conservation of mass:

$$Q = b \int_{z_0}^h U(z) dz \quad (3)$$

where  $b$  is the width.

Substituting Equation 2 into 3 and integrating provides the relationship to calculate  $A$ , given  $Q$ :

$$Q = AbU_h h \left[ \frac{z_0 - h}{h} + \ln \left( \frac{h}{z_0} \right) \right] + bU_h (h - z_0) \left[ 1 - A \ln \left( \frac{h}{z_0} \right) \right] \left( \frac{3t + 1}{2t^2 + 3t + 1} \right) \quad (4)$$

The calculation for parameter  $t$  includes an assumption about the profile shape. According to the velocity profiles measured in a trench by van Rijn, the middepth velocity is approximately equal to the equilibrium middepth velocity given by the logarithmic profile:

$$\frac{\left[ -1 + \ln \left( \frac{h}{z_0} \right) \right]}{\ln \left( 0.5 \frac{h}{z_0} \right)} \approx 0.16t^2 - 0.29t + 1.02 \quad (5)$$

Finally, the quantity  $U_h$  is calculated by the relationship:

$$\frac{dU_h}{dx} = \alpha_1 \frac{U_{h,e}}{h} - \alpha_2 \frac{U_h}{h} \quad (6)$$

where  $x$  is the longitudinal coordinate and  $U_{h,e}$  is the surface velocity for equilibrium flow given by

$$U_{h,e} = \frac{\ln \left( \frac{h}{z_0} \right)}{-1 + \ln \left( \frac{h}{z_0} \right)} \frac{Q}{b} \quad (7)$$

The calculations of parameters  $\alpha_1$  and  $\alpha_2$  are given by empirical relationships derived from flume experiments:

$$\alpha_1 = 0.28 + 0.11 \tanh \left[ 6 \left( \frac{dh}{dx} - 0.15 \right) \right] \quad (8)$$

$$\alpha_2 = 0.235 + 0.065 \tanh \left[ 17 \left( \frac{dh}{dx} - 0.035 \right) \right] \quad (9)$$

### 3 The Model Code

---

The calculation of  $A$  and  $t$  is straightforward, but the integration of the differential equation requires some additional effort:

$$\frac{dU_h}{dx} = \alpha_1 \frac{U_{h,e}}{h} - \alpha_2 \frac{U_h}{h} \quad (10)$$

This numerical integration was carried out using the Runge-Kutta fourth-order scheme. In this method, multiple steps of the relationship were performed:

$$\frac{dU_h}{dx} = f(U_h) \quad (11)$$

where  $f(U_h)$  is defined as the right-hand side of Equation 10. The steps are as follows. Let  $V_0 = U_h(x_0)$  at the initial position:

$$a. Step 1: V_1 = V_0 + \frac{1}{4} \Delta x f(V_0) \quad (12)$$

$$b. Step 2: V_2 = V_1 + \frac{1}{3} \Delta x f(V_1) \quad (13)$$

$$c. Step 3: V_3 = V_2 + \frac{1}{2} \Delta x f(V_2) \quad (14)$$

$$d. Step 4: V_4 = V_3 + \Delta x f(V_3) \quad (15)$$

$$U_h(x_o + \Delta x) = V_4 \quad (16)$$

This method is very precise and stable as long as the length step  $\Delta x$  is not large.

In this model the upstream node is assumed to have a uniform flow velocity; therefore, the model should be started from a location where this is true.

## 4 Summary

---

In this report a simplified numerical model to calculate the vertical velocity profile for changing bed slopes was reviewed. Model predictions were compared to flume data for flow over a mound and a trench. The model is a reasonable planning tool for calculations involving dredging or dredged material disposal sites.

The flume data used were a difficult test for this model. However, the overall profiles compare reasonably well; therefore, the model is judged reliable for planning purposes. Although the model will predict the vertical velocity profiles in riverine and tidal flows, wave action is not included.

In order to effectively use this program, the following information is required by the equations in Chapters 2 and 3 and should be collected within and adjacent to the proposed dredging or dredged material disposal site(s):

- a.* Depth and tide range.
- b.* Velocity: surface, middepth, and bottom.
- c.* Bathymetric conditions.

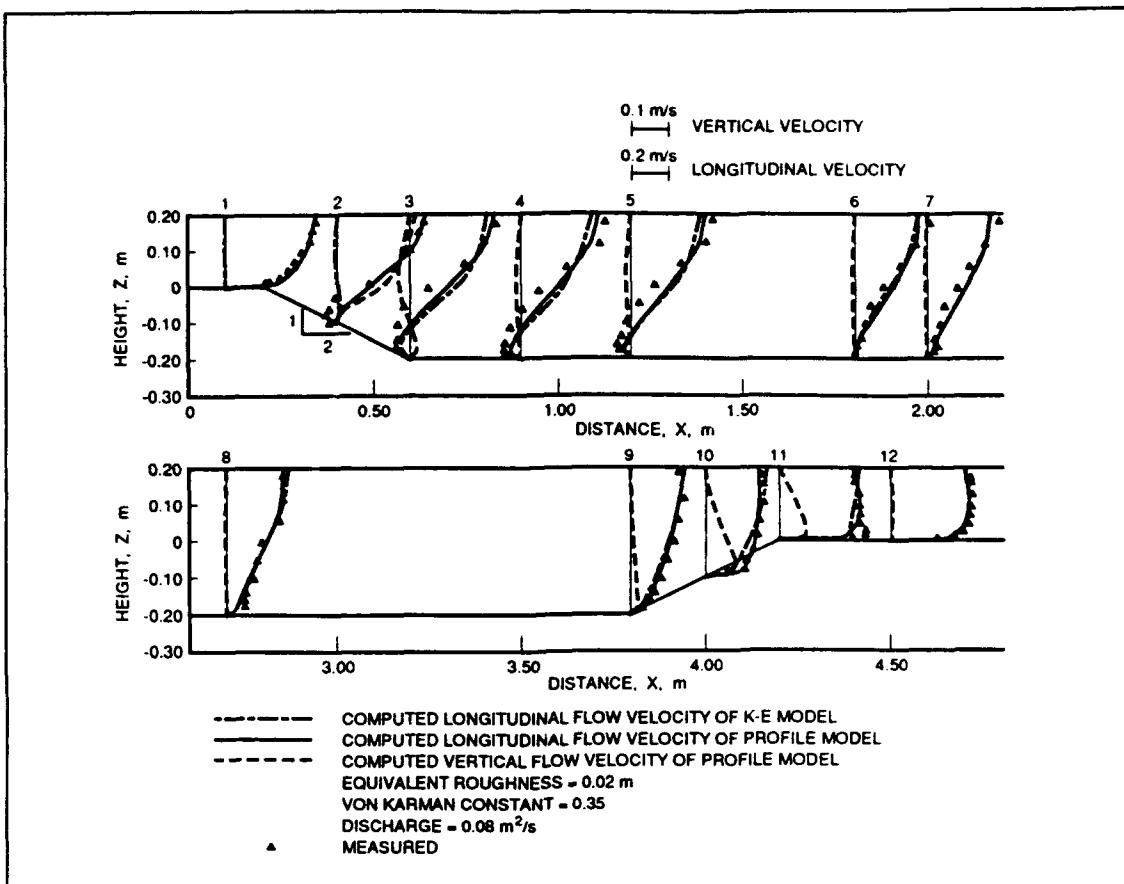


Figure 1. Comparison of the present model, a  $k$ - $\epsilon$  model, and measured data sets according to van Rijn

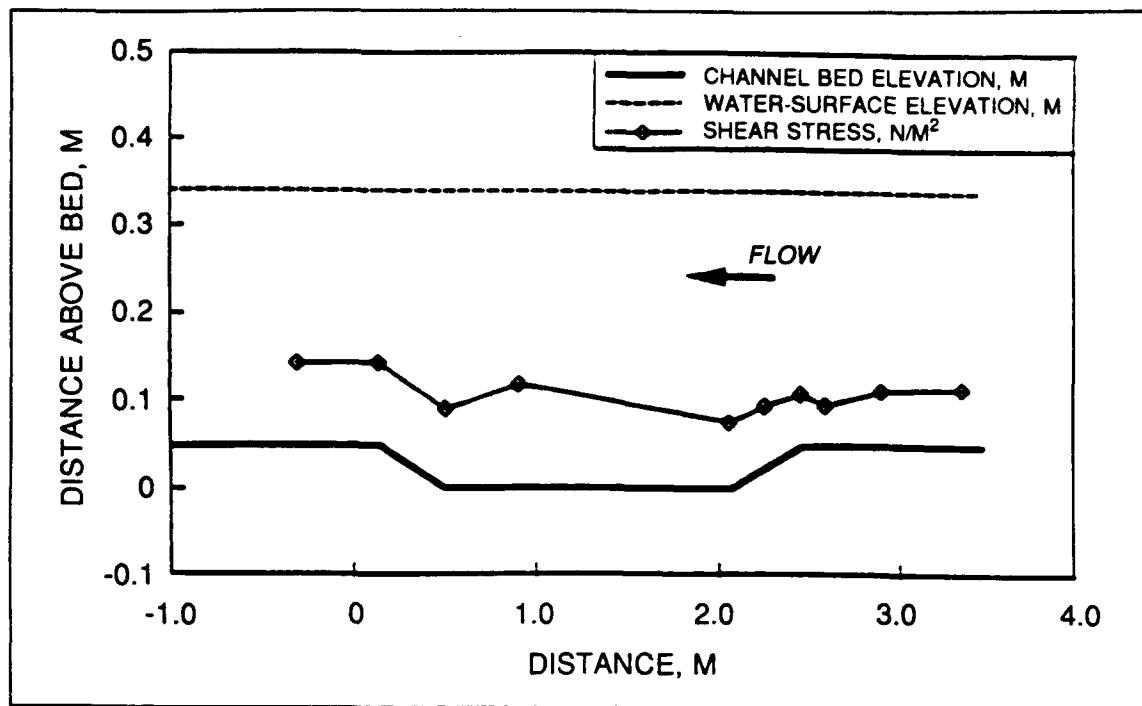


Figure 2. Shear stress for trench test

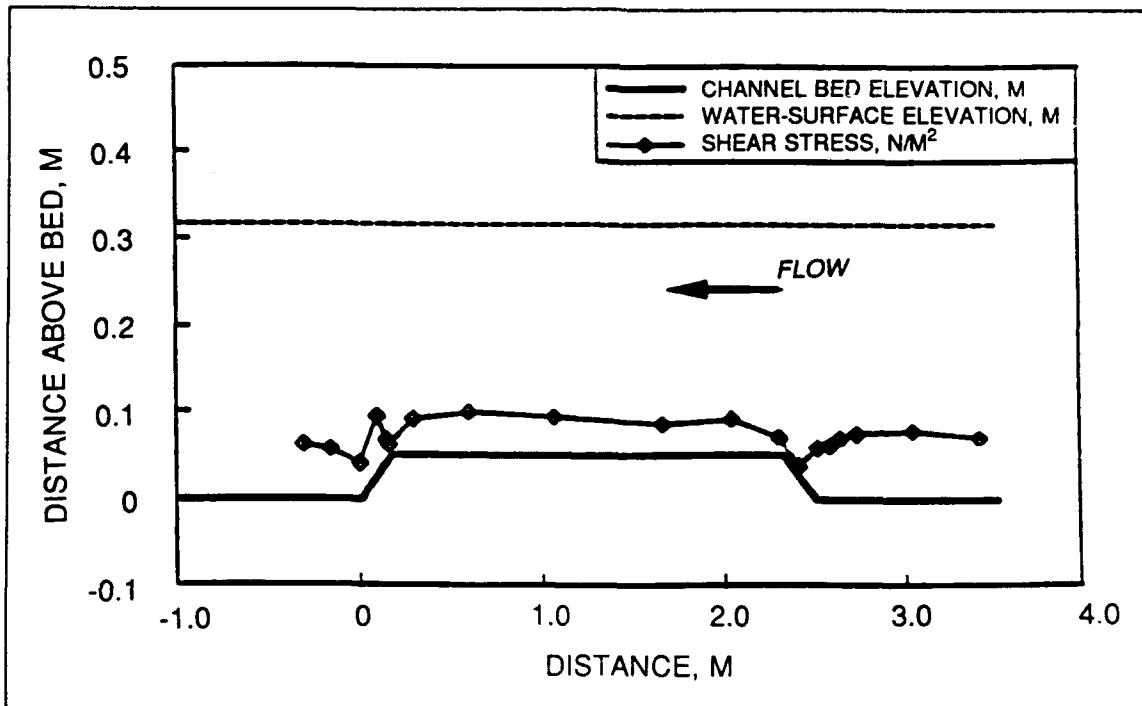


Figure 3. Shear stress for mound test

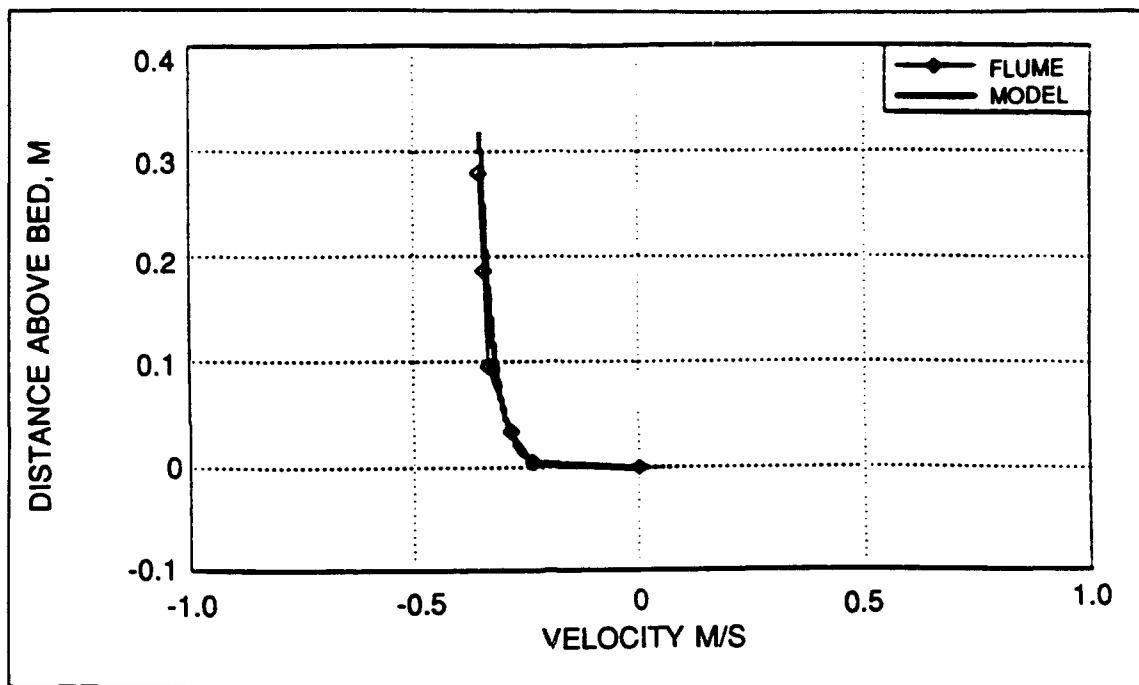


Figure 4. Vertical velocity profile for mound test at 3.35 m

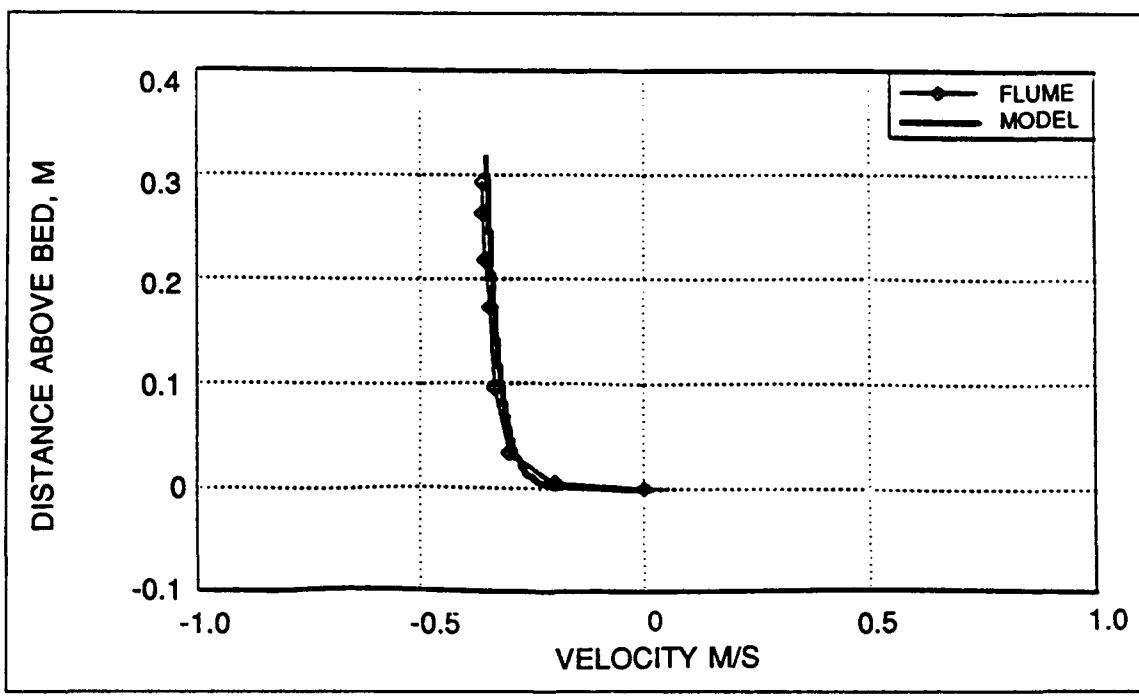


Figure 5. Vertical velocity profile for mound test at 2.68 m

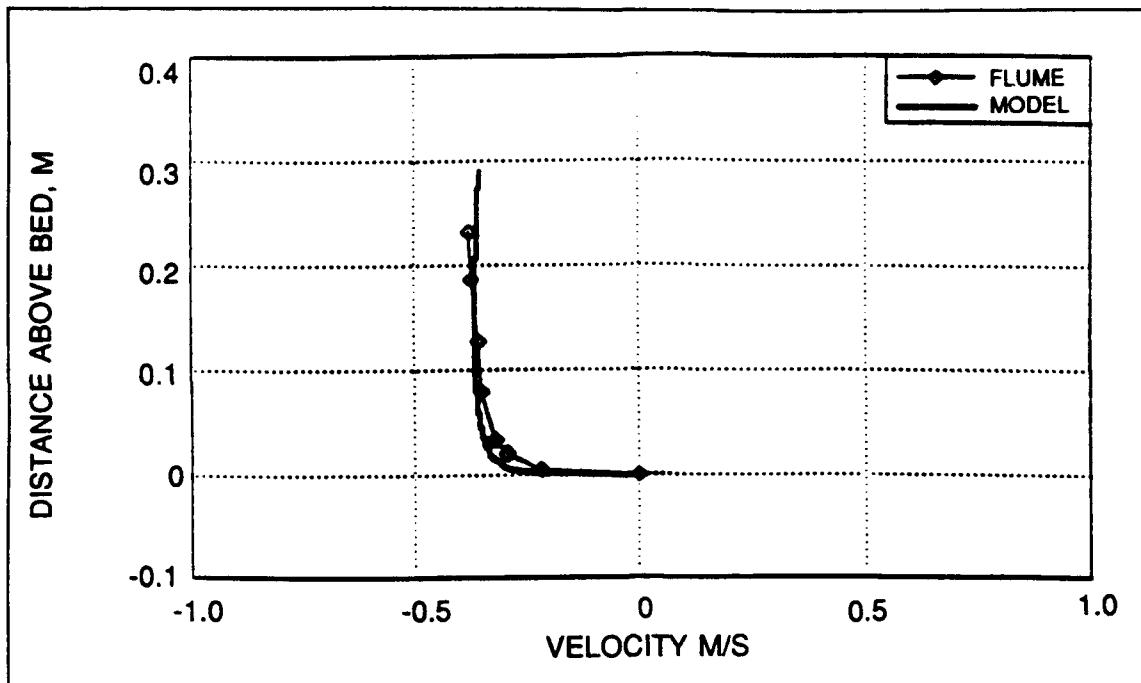


Figure 6. Vertical velocity profile for mound test at 2.41 m

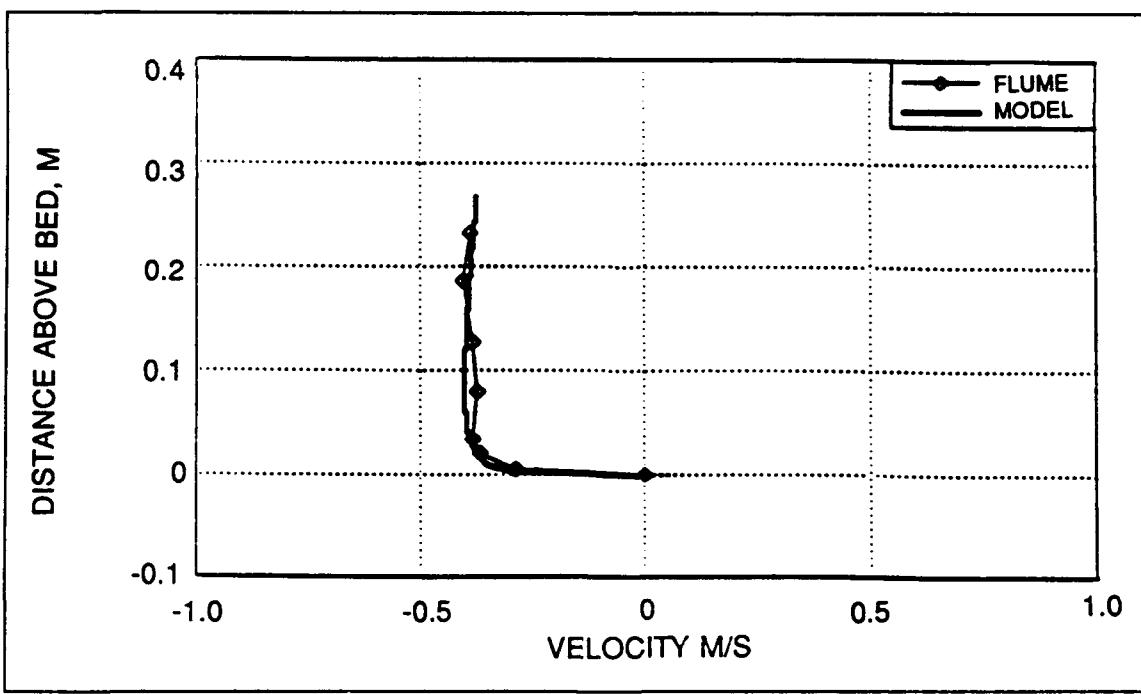


Figure 7. Vertical velocity profile for mound test at 1.98 m

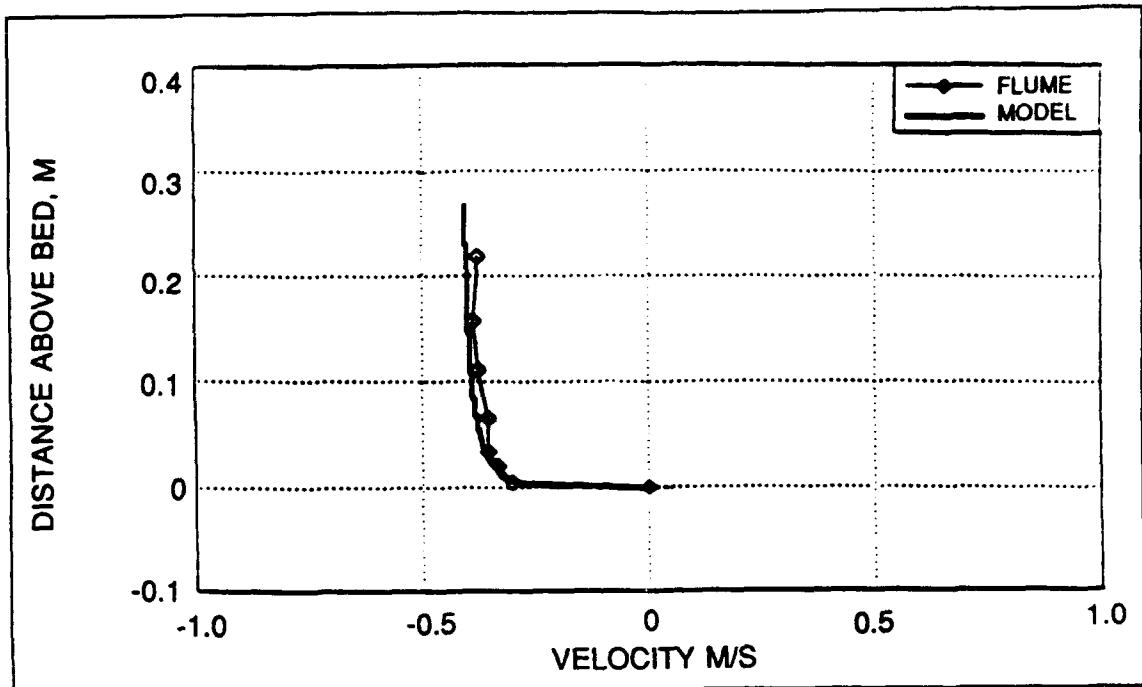


Figure 8. Vertical velocity profile for mound test at 0.61 m

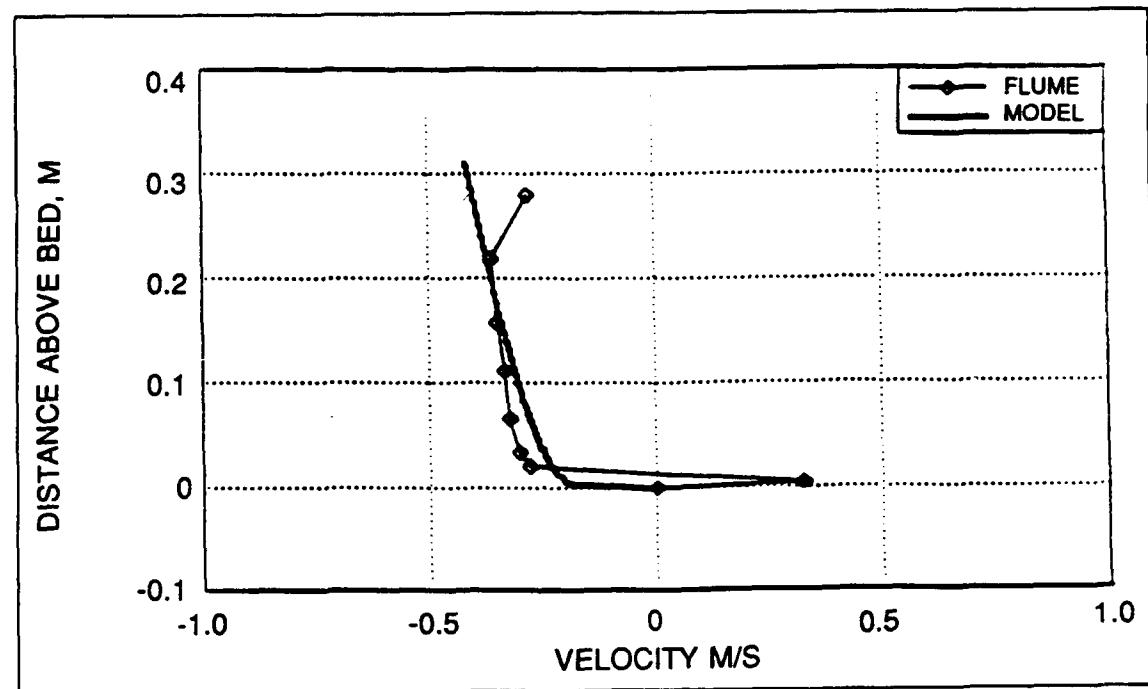


Figure 9. Vertical velocity profile for mound test at 0.0 m

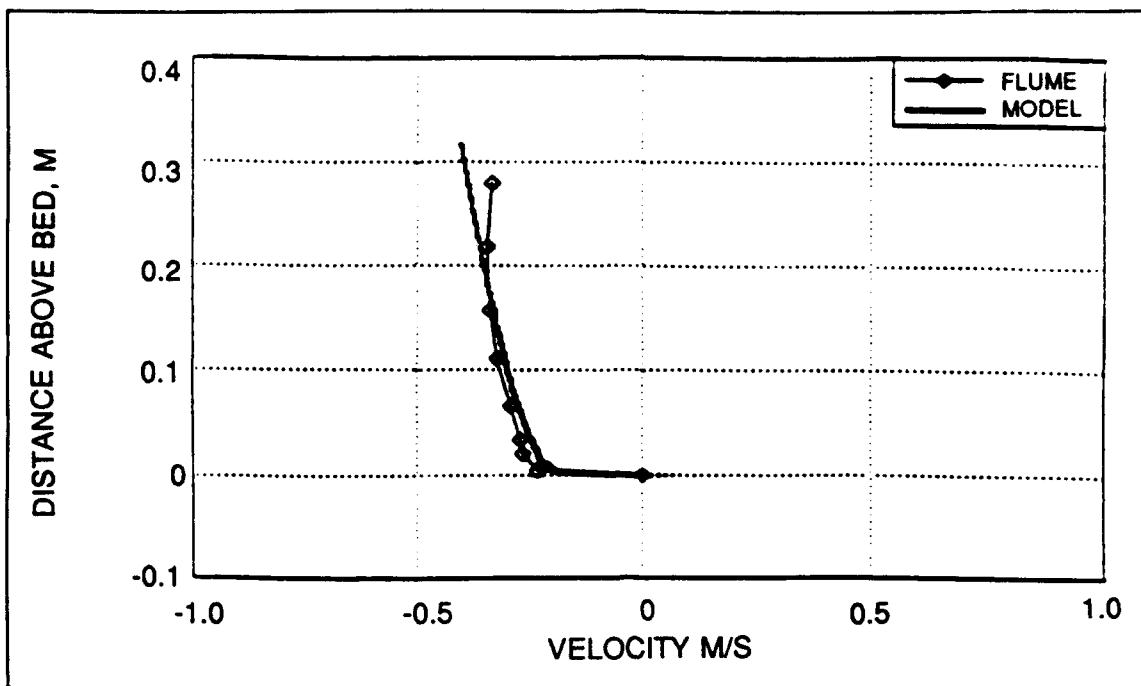


Figure 10. Vertical velocity profile for mound test at -0.30 m

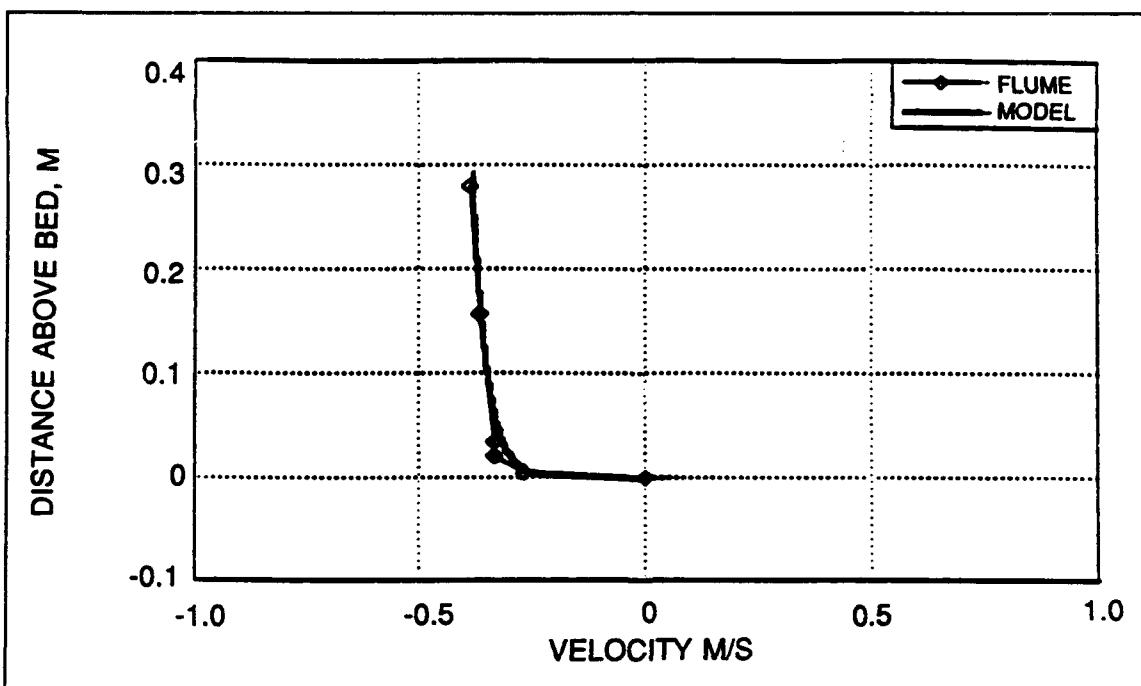


Figure 11. Vertical velocity profile for trench test at 3.35 m

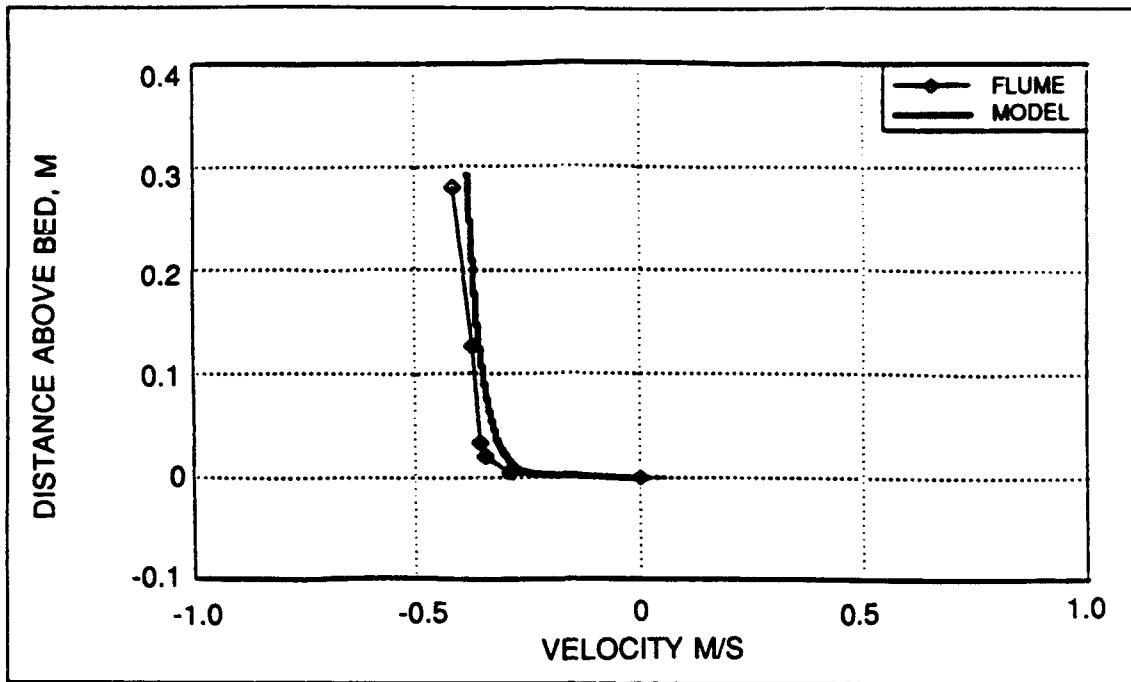


Figure 12. Vertical velocity profile for trench test at 2.59 m

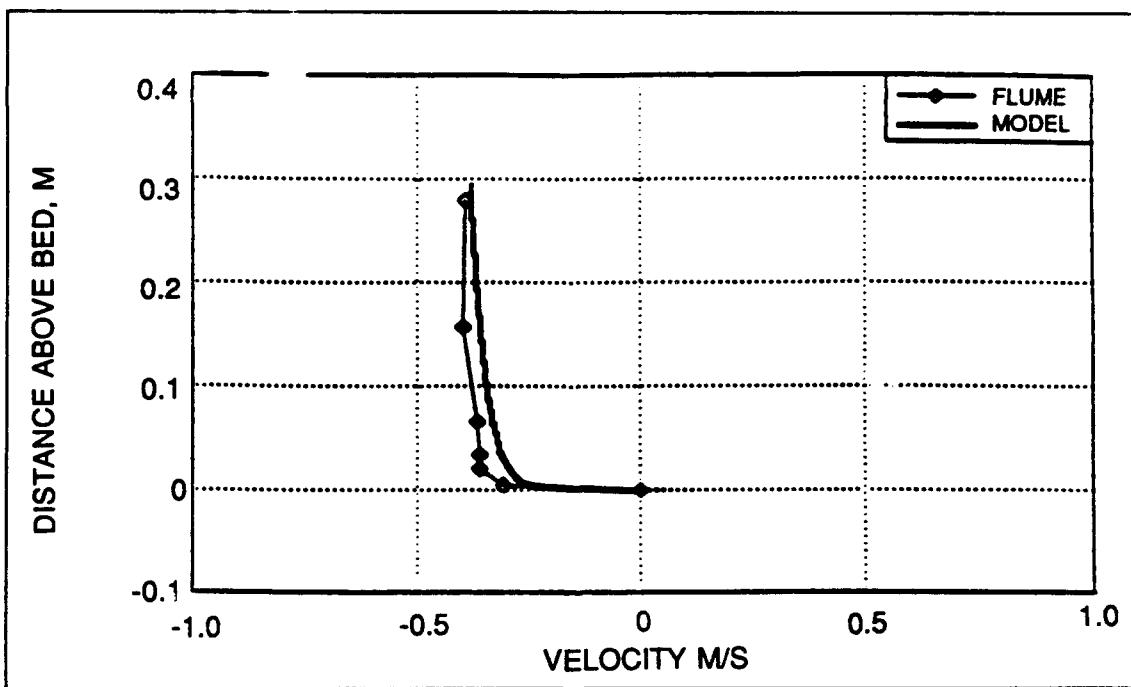


Figure 13. Vertical velocity profile for trench test at 2.43 m

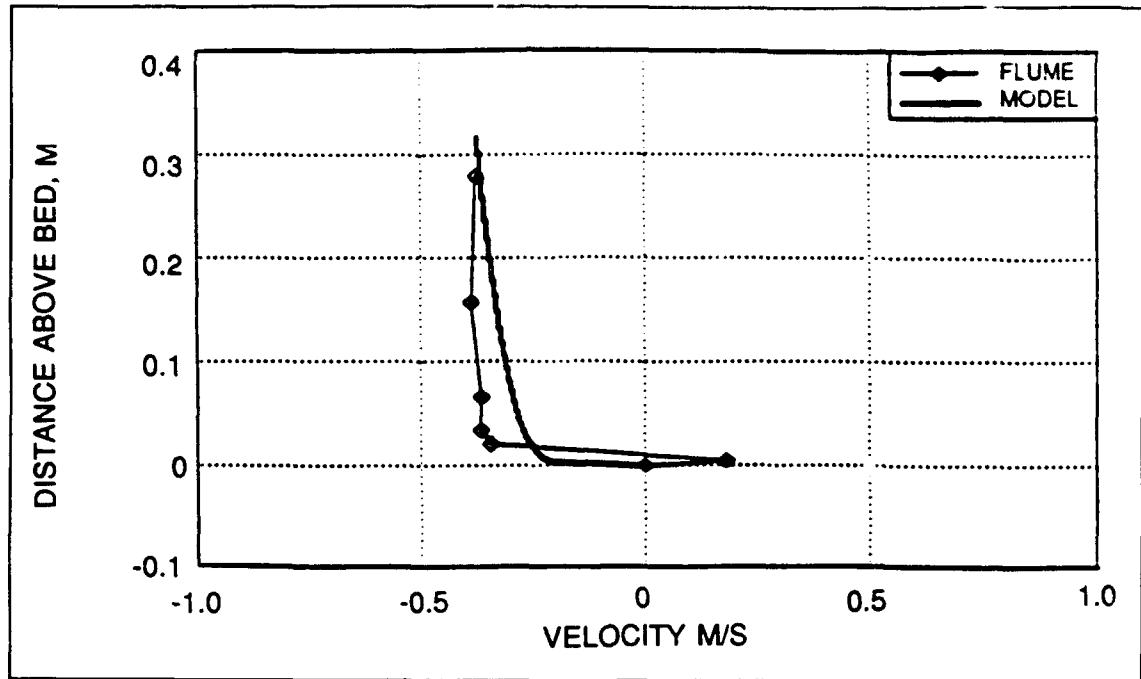


Figure 14. Vertical velocity profile for trench test at 2.26 m

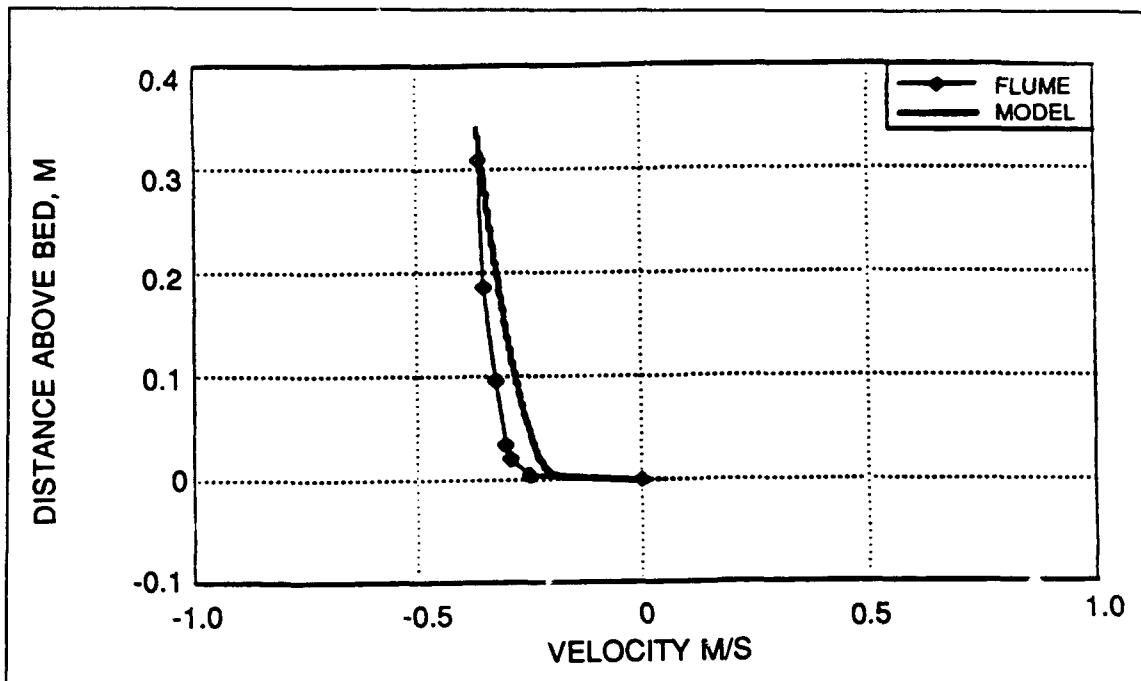


Figure 15. Vertical velocity profile for trench test at 1.74 m

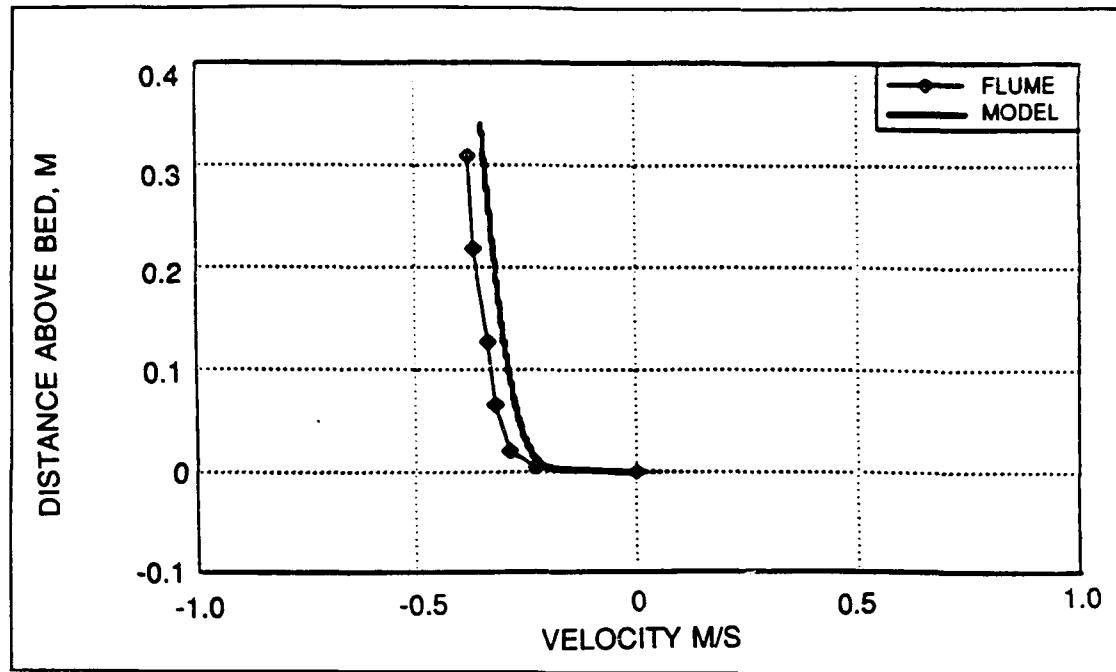


Figure 16. Vertical velocity profile for trench test at 0.61 m

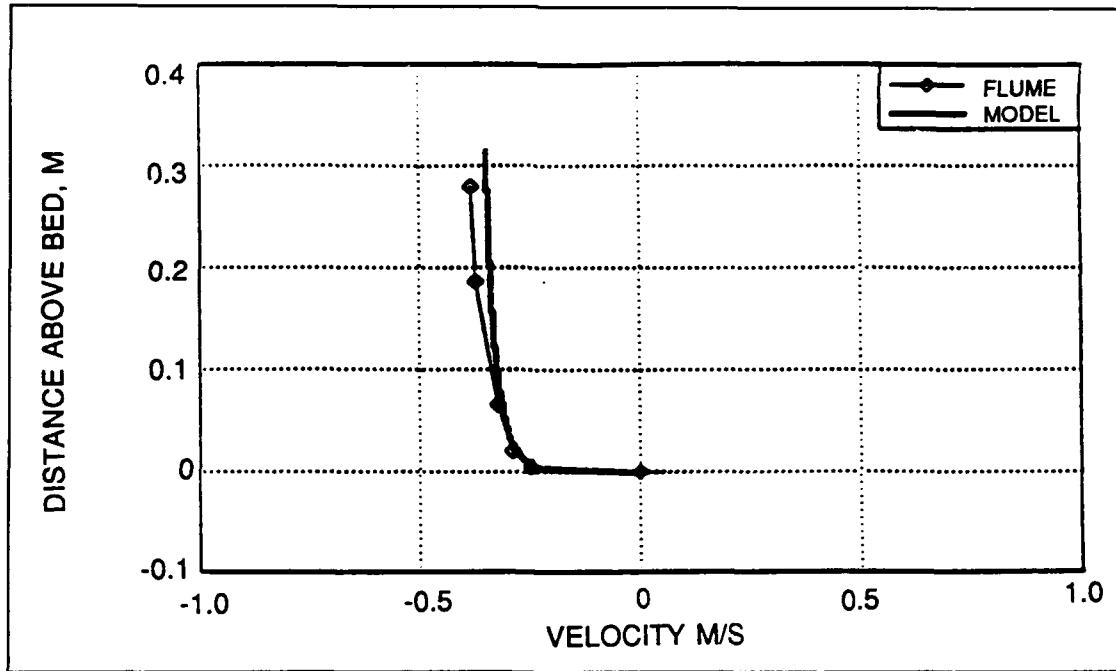


Figure 17. Vertical velocity profile for trench test at 0.52 m

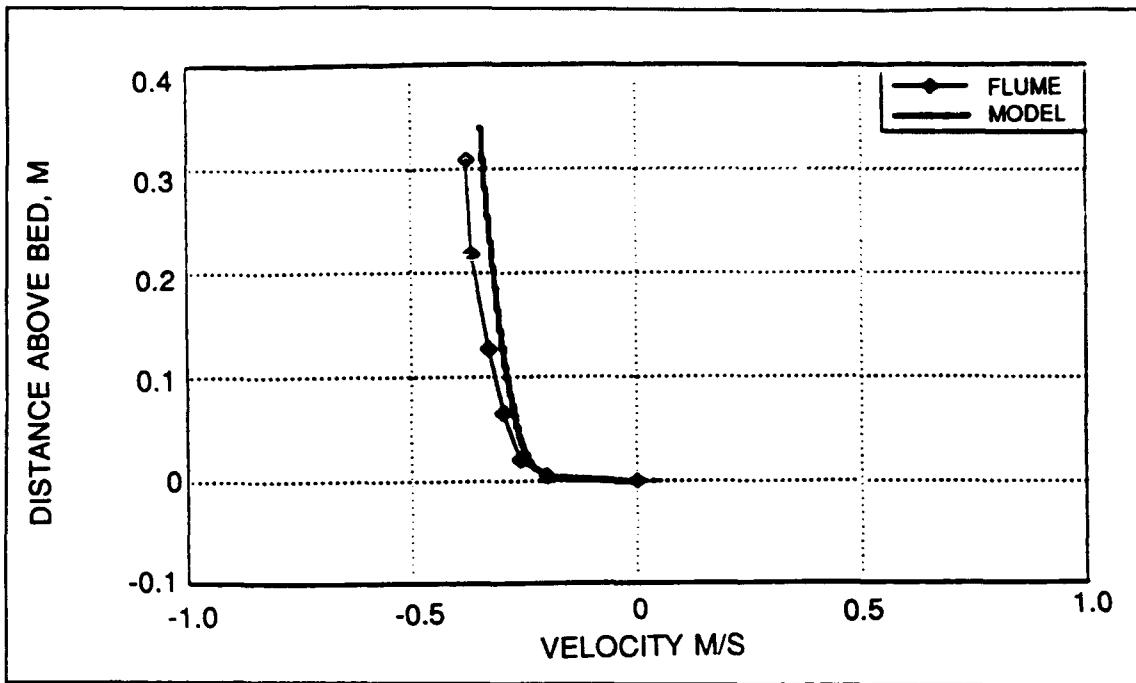


Figure 18. Vertical velocity profile for trench test at 0.30 m

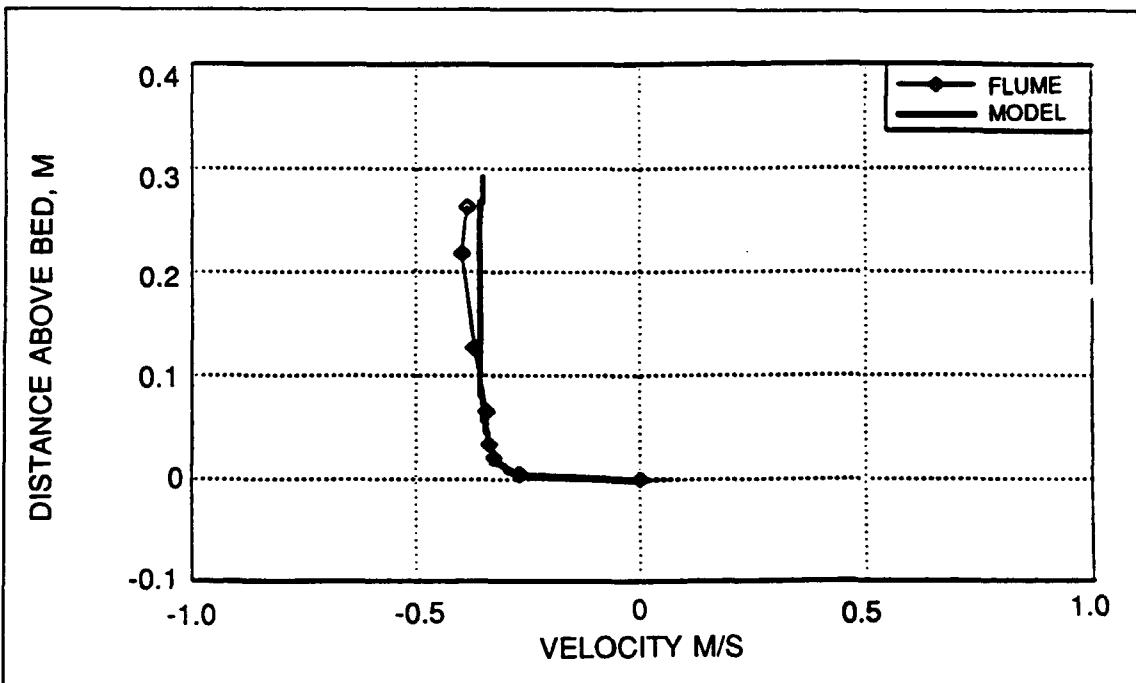


Figure 19. Vertical velocity profile for trench test at 0.0 m

# Appendix A

## Model Stability

---

Since a portion of the model involves spatial integration to calculate the surface velocity  $U_h$ , the model must include a stability limit on the size of a spatial step. This appendix investigates this area and concludes that the limit is great enough that reasonable model application should not be affected. For simplicity, consider the problem:

$$\frac{dU_h}{dx} = \frac{-\alpha_2}{h} U_h \quad (A1)$$

where

$\alpha_2$  = parameter  
 $h$  = depth

Solve for  $U_h$ :

$$U_h(x) = U_h(0) e^{\left(\frac{-\alpha_2}{h} x\right)} \quad (A2)$$

The numerical representation of this calculation is made by the fourth-order Runge-Kutta method. This multistep calculation is made as follows (where for notational simplicity  $U$  will be used to represent  $U_h$  and  $V$  represents intermediate results):

$$V_1 = U_n - \frac{1}{2} \alpha_2 \frac{\Delta x}{h} U_n \quad (A3)$$

$$V_2 = V_1 - \frac{1}{3} \alpha_2 \frac{\Delta x}{h} V_1 \quad (A4)$$

$$V_3 = V_2 - \frac{1}{4} \alpha_2 \frac{\Delta x}{h} V_2 \quad (A5)$$

$$U_{n+1} = V_3 - \alpha_2 \frac{\Delta x}{h} V_3 \quad (A6)$$

The subscript  $n$  stands for the value at the location  $x = n\Delta x$  where  $\Delta x$  is the step length. These steps may be combined into a single step as:

$$U_{n+1} = \frac{(\alpha_2 \frac{\Delta x}{h} - 4)(\alpha_2 \frac{\Delta x}{h} - 3)(\alpha_2 \frac{\Delta x}{h} - 2)(\alpha_2 \frac{\Delta x}{h} - 1)}{24} U_n \quad (A7)$$

For convenience in discussing the growth of round-off errors, assume that  $U_o = 1$ . It is assumed that the round-off error enters the system initially with all other subsequent calculations being exact. The "perturbed" problem will then be written as:

$$U_{n+1}^* = \frac{(\alpha_2 \frac{\Delta x}{h} - 4)(\alpha_2 \frac{\Delta x}{h} - 3)(\alpha_2 \frac{\Delta x}{h} - 2)(\alpha_2 \frac{\Delta x}{h} - 1)}{24} U_n^* \quad (A8)$$

and

$$U_o^* = 1 - \epsilon \quad (A9)$$

where  $\epsilon$  is the initial round-off error.

Subtracting Equation A8 from A7, defining  $E_n = U_n - U_n^*$ , and replacing the multiplier with the symbol  $K$  gives

$$E_{n+1} = KE_n \quad (A10)$$

and

$$E_0 = \epsilon \quad (A11)$$

The growth of the error can be traced back to the initial state since it comes about through the repeated multiplication by  $K$ :

$$E_n = K^n \epsilon \quad (A12)$$

The initial error should decay as movement occurs away from the origin; therefore:

$$|K| < 1 \quad (A13)$$

which in turn requires that

$$\alpha_2 \frac{\Delta x}{h} < 5 \quad (A14)$$

and  $\alpha_2$  has maximum and minimum values of 0.30 and 0.17, respectively. Selecting the most restrictive value of  $\alpha_2 = 0.30$  gives

$$\frac{\Delta x}{h} < 16.16 \quad (A15)$$

It appears that relatively large spatial steps can be taken. However, the smaller steps would be more accurate; and since this is a simple one-dimensional model, high resolution is possible. The spatial step should not be a severe restriction.

# Appendix B

## HPROFILE User's Guide

---

### Software Installation

**Step 1.** Requirements for the installation of HPROFILE:

- a.* IBM-PC (AT or XT) compatible personal computer (PC), with either 80286 or 80386 processor, 640K of memory, MS/DOS version 3.0 or later operating system, VGA or EGA color monitor. A math coprocessor is recommended for faster operation, but is not necessary.
- b.* Hard disk.
- c.* Diskette (floppy disk), 5.25- or 3.5-in. with the following files:

HPROFILE.EXE  
DEMO.DAT

**Step 2.** Turn on the computer or use the MS/DOS command to change directory (CD\ ) to the system prompt as shown:

C:\>CD\ <RETURN>

**Step 3.** Using the DOS command MD (Make Directory), create a new subdirectory in the root directory for the HPROFILE program as shown:

C:\>MD\HPROFILE <RETURN>

**Step 4.** Next, type CD\HPROFILE <RETURN> to move into the newly created subdirectory. The prompt will now be C:\HPROFILE.

**Step 5.** Place the diskette into Drive A or B. Use the DOS copy command to copy the required files onto the subdirectory as shown:

C:\>HPROFILE COPY A:\*.\* or C:\>HPROFILE COPY B:\*.\*

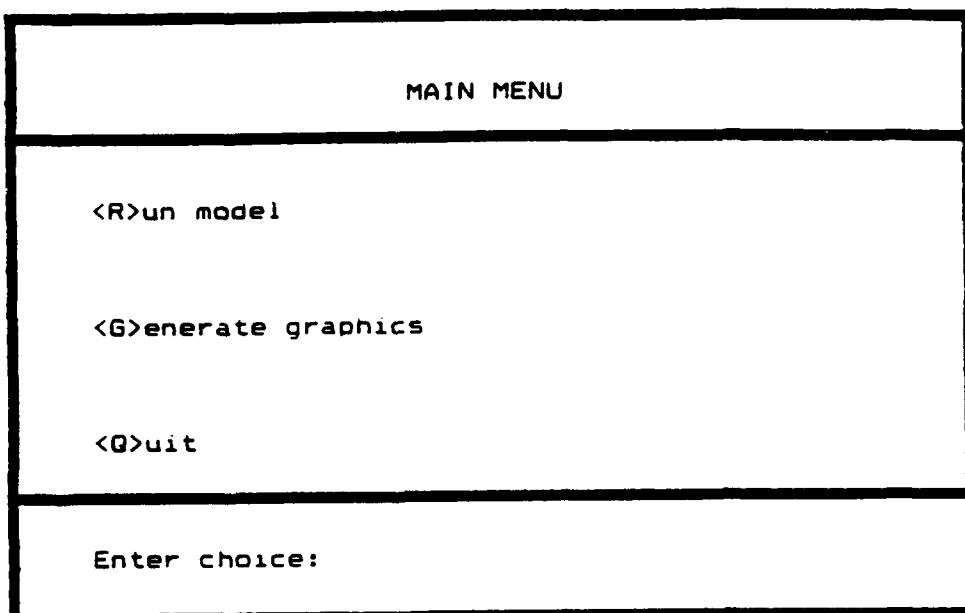
**Step 6.** The message "2 files have been copied" will be displayed after the files have been copied. To verify, use the DOS command to look in the directory by typing **DIR** and <RETURN>.

**Step 7.** HPROFILE is now installed in the computer. Remove the diskette from the drive, and store in a safe location away from the computer. The rest of this guide provides additional guidance on the model operation.

## Model Operation

**Step 1.** To execute HPROFILE, move to the HPROFILE subdirectory.

**Step 2.** HPROFILE is a completely menu-driven system. Type **HPROF**, and the main menu will appear on your monitor with the following three options:



**Step 3.** To make a selection, press the corresponding key, which is in brackets. Note: Either uppercase or lowercase letters can be used.

## Main Menu Option Descriptions

### <R>un model

Before the model can be executed, the data file must be prepared. The data file should be an ASCII file with the following four columns of data: location of nodes (x), distance above bed, bed slope  $dh/dx$ , and zero velocity bed

elevation. The data file should be on the hard disk of your computer or loaded on a floppy disk drive. An example input file is given in Table B1.

Immediately after the run option is selected in the main menu, the following model parameter menu will appear with the default values for the data set DEMO.DAT entered:

| MODEL PARAMETERS                     |  |
|--------------------------------------|--|
| (1) Project name <u>demo</u>         |  |
| (2) Input filename <u>demo.dat</u>   |  |
| (3) Number of X locations <u>22</u>  |  |
| (4) Width (m) <u>1.0</u>             |  |
| (5) Discharge (cu m/sec) <u>.104</u> |  |
| (6) All values correct...Run model   |  |
| Enter choice:                        |  |

To change a parameter value, enter the number of the option; the cursor will erase the old value. Enter the new value followed by <RETURN>. While entering parameters please make note of the following:

- a. The project name will be used as the name of the result file generated by HPROFILE. Make sure no existing file has this name because HPROFILE will destroy the file's contents when generating the result file.
- b. The project name and input file name must be less than 12 characters long including .EXT

- c. The units listed by the values are the only units HPROFILE will use.
- d. There may be no more than 25 nodes in one execution.
- e. Any wrong entry can be changed by choosing that entry a second time and entering the correct value.

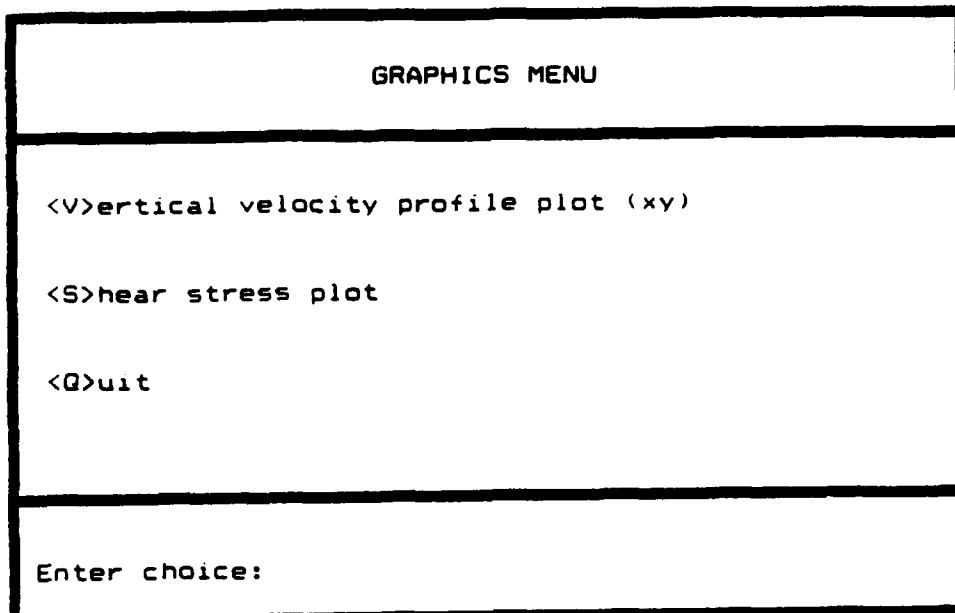
When you are satisfied with the model parameters entered, choose selection **6** to run the model. The message "Executing model" will flash on a blue screen.

Next you will be asked if you wish to calculate vertical velocity profiles. Enter **Y** for yes, and the prompt "Node = " will appear on another screen. Enter the number of the node the vertical velocity profile will be calculated for followed by <RETURN>. You will now be asked for the number of points along the vertical for which velocities should be calculated. Enter the number and press <RETURN>. This number should be less than 25. The profile will be echoed on the screen along with the shear stress at the node selected. When you are ready to continue, press **C** <RETURN>.

You will be asked again if you wish to calculate a vertical velocity profile. Enter **N** for no when you have calculated all the profiles you wish to for the current parameter set. The main menu will reappear on the screen and the result file will be complete and will be saved under the project name. An example results file is given in Table B2.

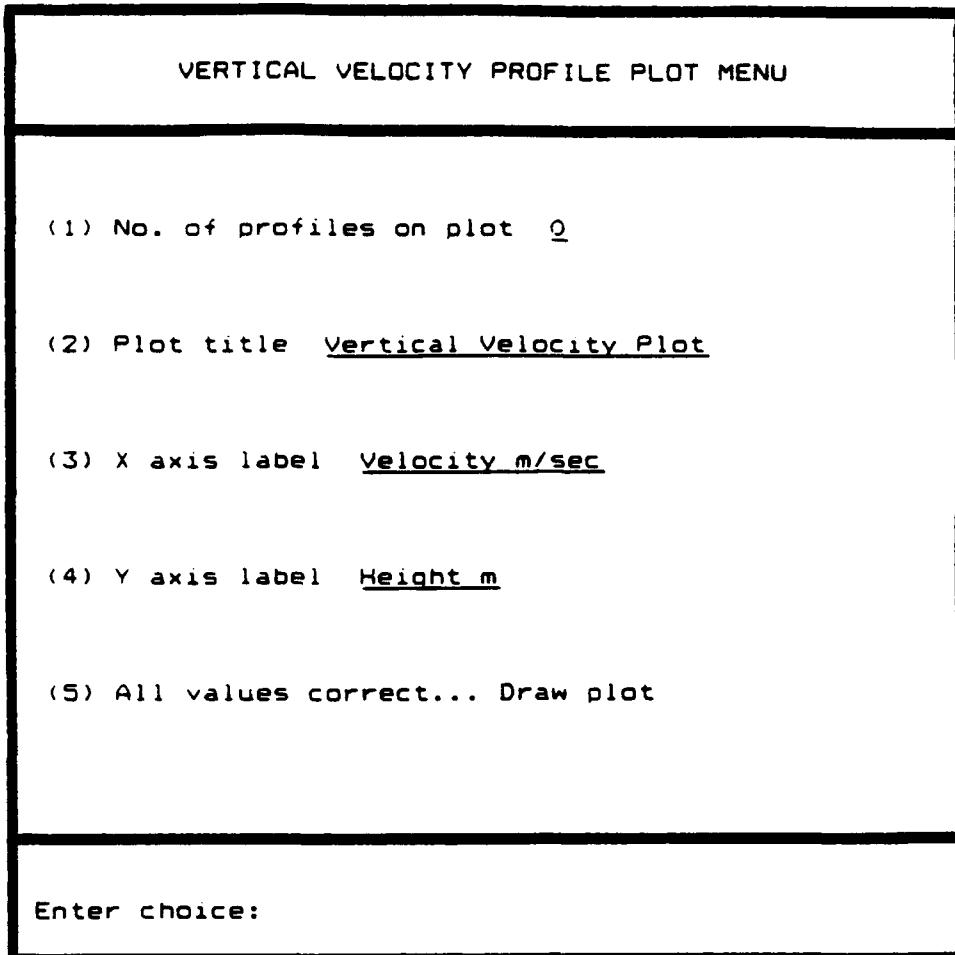
#### **<G>enerate graphics**

Two types of graphs are available with HPROFILE: x-y plots of vertical velocity profiles and x-y plots of the shear stress at each node along the range of the bed. When the graphics selection is made, the following menu will be displayed on the screen:



When a graph type has been selected, the current project name will appear on the screen and you can choose to accept the project or change to a new project. To change projects, enter **C** and the cursor will erase the old project name. Enter the new project name and press **<RETURN>**. The project name must be the name of a result file generated by HPROFILE. When the project name is acceptable, press **A** to accept the project and continue.

To generate a vertical velocity profile plot, press **V <RETURN>**. The project screen will appear. Enter the correct project name or accept the current project. The next screen will allow you to enter parameters for the plot and is called the "Vertical Velocity Profile Plot Menu."

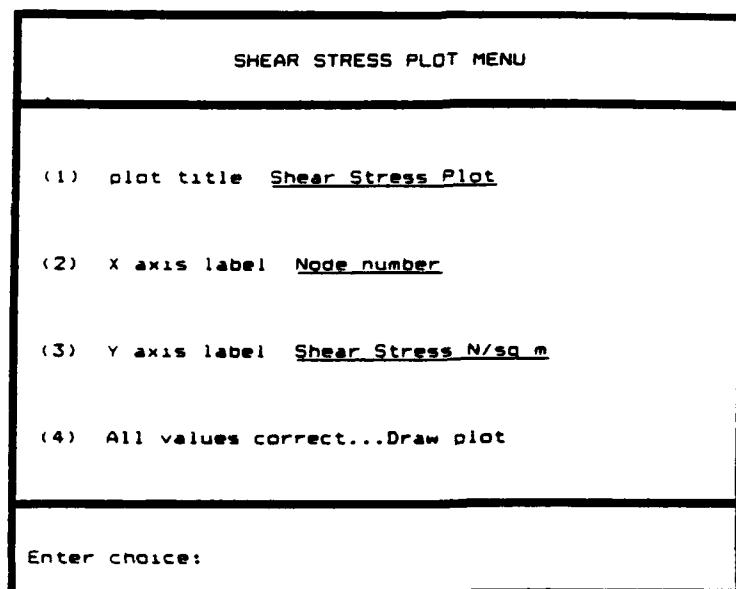


Choice 1 allows you to specify how many profiles will appear on the plot. You may have up to five profiles on one plot. The data for each profile are generated during execution. Only profiles for nodes specified individually at the "Calculate vertical velocity profile" prompt are generated; therefore, only profiles for those nodes may be plotted. After you have entered the number of profiles to appear on the plot, another menu will appear that allows you to enter the node numbers for each profile on the plot and the description that

will appear in the legend (must be 25 characters or less). When you have entered the values for each profile, you will be asked if these values are correct. If they are not correct, choose the appropriate response, and you will be asked if you want to change a node or legend value. Type *N* <RETURN> to change a node value or *L* <RETURN> to change a legend value. Next you will be asked which node or legend value you wish to change. Enter the correct number and you will be allowed to make the change. Be careful not to accidentally press the <ESC> key or any function keys as they may distort the appearance of the screen. When all values are correct, choose the appropriate selection, and the "Vertical Velocity Profile Plot Menu" will return to the screen.

Choice 2 allows you to enter the plot title. It may be up to 40 characters long. Choices 3 and 4 allow you to label the x-axis and the y-axis. Regardless of the labels entered in this menu, velocity is plotted in units of meters per second along the x-axis, and the vertical level of the velocity is plotted in meters along the y-axis. Any wrong entries can be corrected by selecting the entry a second time and entering the correct value. Choose 5 to draw the plot. A message will appear on the screen asking where the plot should be drawn; choose *D* and the plot will appear on your monitor. If for some reason HPROFILE cannot find the vertical velocity profile section of the result file of the specified project for a particular node requested, the message "Some data not available" will appear on the monitor and HPROFILE will return to the graphics menu. Check the result file to verify which nodes profiles were generated for. These are the only nodes that can appear on the vertical velocity profile plots. Figure B1 shows an example vertical velocity profile plot.

To choose a shear stress plot, press *S* <RETURN>. The project selection will appear, and after you have selected the correct project, the "Shear Stress Plot Menu" will appear.



The shear stress plot displays the shear stress at each node along the bed on the y-axis against the node number along the x-axis. To change the plot title or axes labels, choose the appropriate selection. To correct an entry, select the wrong entry and enter the correct value. When all values are satisfactory, enter 4 to view the plot. Enter **D** in response to the prompt for the plotting surface and the plot will appear on your monitor. If the message "Some data not available" appears on the screen, check the project result file to see if it contains the proper amount of data for each node in the range. Figure B2 shows a sample result file.

When the plots (velocity and shear stress) appear on the screen, the options "quit," "read," "zoom," and "print" also appear. To find out the y-value for a given x-value, press **R** or move to the "read" option using the arrow keys and press <RETURN>. Then enter the x-value of the point you want and press <RETURN>. The corresponding y-values for each curve will be printed at the bottom of the screen. Press <RETURN> and the original four options will be displayed.

To enlarge a specific area of the plot, press **Z** or move to the "zoom" option using the arrow keys. Press <RETURN> and choose "window" and press <RETURN> again. Imagine a rectangle encompassing the area to enlarge and place the cursor on one corner of the rectangle; press <RETURN>. Move the cursor to the opposite corner of the rectangle and press <RETURN> again (this process is called "rubber banding"). The screen will be redrawn with the portion of the plot enclosed in the rectangle or "window" enlarged in the plotting area. You may use zoom again to enlarge a portion of this window or you may use the "zoom, all" option to return to the original plot.

The "print" option executes a screen dump to a graphics printer. To exit the plot, press **Q** and the program will return to the HPROFILE graphics menu.

The "Quit" selection in the graphics menu will return HPROFILE to the main menu.

**Table B1****EXAMPLE INPUT DATA FOR HPROFILE**

| <u>X LOCATION</u> | <u>DISTANCE ABOVE BED</u> | <u>DH/DX</u> | <u>ZERO VELOCITY BED ELEVATION</u> |
|-------------------|---------------------------|--------------|------------------------------------|
| -3.3528           | 0.317                     | 0.0          | .000001                            |
| -2.98704          | 0.317                     | 0.0          | .000001                            |
| -2.68224          | 0.317                     | 0.0          | .000001                            |
| -2.52984          | 0.317                     | 0.0          | .000001                            |
| -2.48716          | 0.3109                    | -0.2857      | .000001                            |
| -2.41402          | 0.29001                   | -0.2857      | .000001                            |
| -2.3516           | 0.27217                   | -0.2857      | .000001                            |
| -2.3165           | 0.2662                    | 0.0          | .000001                            |
| -2.2000           | 0.2662                    | 0.0          | .000001                            |
| -1.9812           | 0.2662                    | 0.0          | .000001                            |
| -1.6764           | 0.2662                    | 0.0          | .000001                            |
| -1.3500           | 0.2662                    | 0.0          | .000001                            |
| -1.0668           | 0.2662                    | 0.0          | .000001                            |
| -0.6096           | 0.2662                    | 0.0          | .000001                            |
| -0.3048           | 0.2662                    | 0.0          | .000001                            |
| -0.1978           | 0.2662                    | 0.0          | .000001                            |
| -0.1578           | 0.27191                   | 0.2857       | .000001                            |
| -0.09754          | 0.28913                   | 0.2857       | .000001                            |
| -0.02             | 0.31129                   | 0.2857       | .000001                            |
| 0.02              | 0.317                     | 0.0          | .000001                            |
| 0.1524            | 0.317                     | 0.0          | .000001                            |
| 0.3048            | 0.317                     | 0.0          | .000001                            |

Table B2

## SAMPLE RESULT FILE MPROFILE

Project demo  
 Input file = demo.dat  
 There are 22 I locations  
 Width (m) = 1.0  
 Discharge (cu m/sec) = .104

| NODE | I LOCATION | DISTANCE<br>ABOVE BED | SURFACE<br>VELOCITY | A        | T       | ZERO BED<br>ELEVATION | SHEAR    |
|------|------------|-----------------------|---------------------|----------|---------|-----------------------|----------|
|      |            |                       |                     |          |         |                       | STRESS   |
| 1    | -3.352800  | .317000               | .356196             | .078947  | .174050 | .000001               | .1147329 |
| 2    | -2.987040  | .317000               | .356521             | .080573  | .174050 | .000001               | .1146161 |
| 3    | -2.682240  | .317000               | .356739             | .081667  | .174050 | .000001               | .1145374 |
| 4    | -2.529840  | .317000               | .356834             | .082140  | .174050 | .000001               | .1145034 |
| 5    | -2.487160  | .310900               | .357039             | .048050  | .174228 | .000001               | .1194153 |
| 6    | -2.414020  | .290010               | .358517             | -.075394 | .174870 | .000001               | .1376804 |
| 7    | -2.351600  | .272170               | .360798             | -.190102 | .175462 | .000001               | .1553841 |
| 8    | -2.316500  | .266200               | .362512             | -.226465 | .175671 | .000001               | .1615578 |
| 9    | -2.200000  | .266200               | .367887             | -.195870 | .175671 | .000001               | .1593817 |
| 10   | -1.981200  | .266200               | .376794             | -.147101 | .175671 | .000001               | .1563077 |
| 11   | -1.676400  | .266200               | .386992             | -.094011 | .175671 | .000001               | .1523586 |
| 12   | -1.350000  | .266200               | .395608             | -.051296 | .175671 | .000001               | .1493914 |
| 13   | -1.066800  | .266200               | .401547             | -.022916 | .175671 | .000001               | .1472080 |
| 14   | -.609600   | .266200               | .408826             | .010738  | .175671 | .000001               | .1445324 |
| 15   | -.304800   | .266200               | .412459             | .027094  | .175671 | .000001               | .1431967 |
| 16   | -.197800   | .266200               | .413550             | .031946  | .175671 | .000001               | .1427959 |
| 17   | -.157800   | .271910               | .416869             | .084926  | .175471 | .000001               | .1351127 |
| 18   | -.097540   | .289130               | .419546             | .202110  | .174898 | .000001               | .1163182 |
| 19   | -.020000   | .311290               | .420155             | .323238  | .174217 | .000001               | .0963084 |
| 20   | .020000    | .317000               | .418597             | .345491  | .174050 | .000001               | .0922566 |
| 21   | .152400    | .317000               | .413715             | .327535  | .174050 | .000001               | .0940152 |
| 22   | .304800    | .317000               | .408578             | .308181  | .174050 | .000001               | .0958655 |

## VERTICAL VELOCITY PROFILE

NODE = 10

NUMBER OF POINTS ALONG THE VERTICAL = 10

ZERO VELOCITY BED ELEVATION = .000001

| I LOCATION | DISTANCE<br>ABOVE BED | ETA     | VELOCITY |
|------------|-----------------------|---------|----------|
| 1          | -1.98120              | .026621 | .10000   |
| 2          | -1.98120              | .053241 | .20000   |
| 3          | -1.98120              | .079861 | .30000   |
| 4          | -1.98120              | .106481 | .40000   |
| 5          | -1.98120              | .133100 | .50000   |
| 6          | -1.98120              | .159720 | .60000   |
| 7          | -1.98120              | .186340 | .70000   |
| 8          | -1.98120              | .212960 | .80000   |
| 9          | -1.98120              | .239580 | .90000   |
| 10         | -1.98120              | .266200 | 1.00000  |

SHEAR STRESS = .1563077 N/sq m

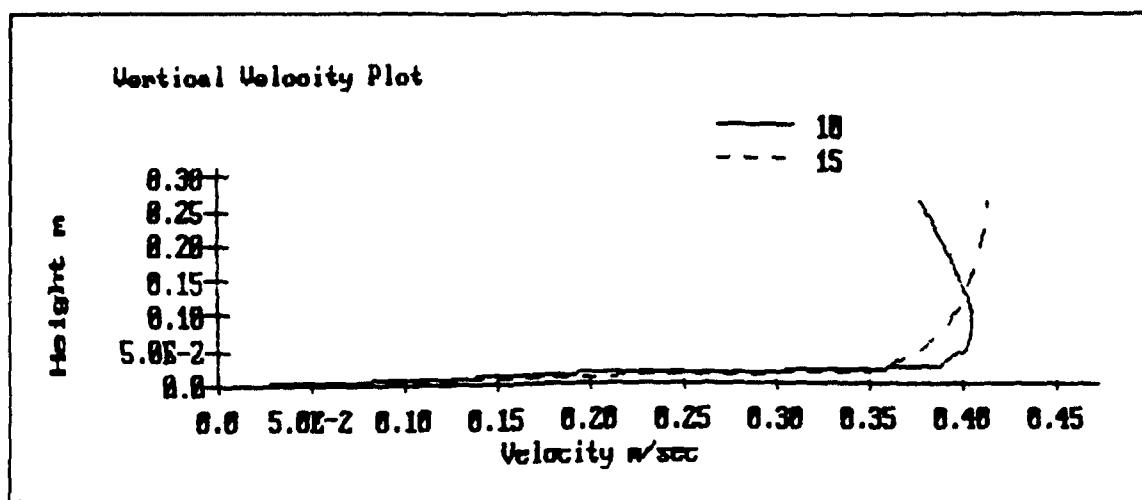


Figure B1. Example vertical velocity plot

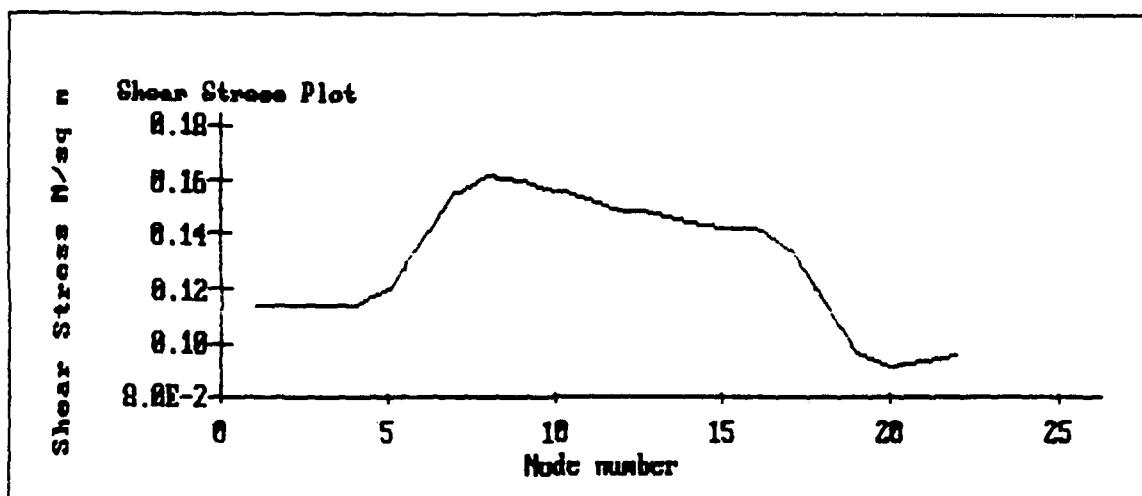


Figure B2. Example shear stress plot

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

|   |   |  |   |   |
|---|---|--|---|---|
| <b>1. AGENCY USE ONLY (Leave blank)</b>   |   |  | <b>2. REPORT DATE</b><br>September 1993   | <b>3. REPORT TYPE AND DATES COVERED</b><br>Final Report |
| <b>4. TITLE AND SUBTITLE</b><br><br>Use of a Simple Model to Calculate Velocity Profiles Over Changing Bed Slopes   |   |  | <b>5. FUNDING NUMBERS</b><br><br>WU 32590   |   |
| <b>6. AUTHOR(S)</b><br>R. C. Berger<br>Allen M. Teeter<br>Walter Pankow   |   |  | <b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>   |   |
| <b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b><br><br>U.S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199  |   |  | <b>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</b><br><br>Miscellaneous Paper DRP-93-1   |   |
| <b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br>Department of the Army, U.S. Army Corps of Engineers Washington, DC 20314-1000  |   |  | <b>11. SUPPLEMENTARY NOTES</b><br><br>Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. |   |
| <b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b><br><br>Approved for public release; distribution is unlimited.  |   |  | <b>12b. DISTRIBUTION CODE</b>   |   |
| <b>13. ABSTRACT (Maximum 200 words)</b><br><br>This report describes a simple numerical model operated on a personal computer (PC) to predict velocity differences caused by changes in bathymetry. The model results were compared to various flume tests, and the model appears reasonable for use as a planning tool for calculations at dredged material disposal sites. The model is intended to allow engineers to calculate the local velocities for the pre- and post-dredged material placement conditions to determine whether the material would be eroded and transported away from the disposal site. The model (HPROFILE) predicts the vertical velocity profile at various depths in the riverine- and tide-dominant flows. A mathematical proof of the model stability (Appendix A) and a user's guide (Appendix B) are included. |   |  |   |   |
| <b>14. SUBJECT TERMS</b><br>Bathymetry<br>Dredged material disposal sites<br>Numerical model  |   |  | <b>15. NUMBER OF PAGES</b><br>40  |   |
|   |   |  | <b>16. PRICE CODE</b>   |   |
| <b>17. SECURITY CLASSIFICATION OF REPORT</b><br>UNCLASSIFIED  | <b>18. SECURITY CLASSIFICATION OF THIS PAGE</b><br>UNCLASSIFIED | <b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> | <b>20. LIMITATION OF ABSTRACT</b>   |   |